Theoretical Studies of Underdoped Cuprates

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- My research is chiefly focused on the fundamental aspects of high temperature superconductivity in cuprate oxides. Understanding the phase diagram of the cuprates is one of the most challenging issues in condensed matter physics. It has been well established experimentally over the past few years that the largest region on the phase diagram is the pseudogap phase in which numerous system properties are like in a superconductor, yet superconductivity is absent. Understanding the origin of this psedogap is the most crucial step in understanding the mechanism for high-temperature superconductivity.

- My approach to the cuprates is based on the idea that the superconducting and the pseudogap phases emerge due to strong interaction between fermions and their own collective magnetic excitations that are ultimately responsible for antiferromagnetism of parent compounds of high temperature superconductors.

- Working along these lines, we developed the theory for the spin-fermion interaction in the strong coupling regime. The theory presents a three-step explanation of the physics of the cuprates:
  - In the normal state, we found a broad region near antiferromagnetic transition where the system behavior is highly unconventional (non Fermi liquid) in that fermions propagate diffusively rather than ballistically.
  - The onset temperature of the pairing of this diffusive fermions is rather high, and the region where fermions are paired into spin singlets occupies the large portion of the phase diagram.
  - We found that the pairing of diffusive fermions opens up a pseudogap in the electronic spectrum but does not give rise to a true superconductivity. The latter requires conventional Fermi liquid behavior and exists only in a much smaller region of the phase diagram that shrinks as the system approaches an antiferromagnetic transition.

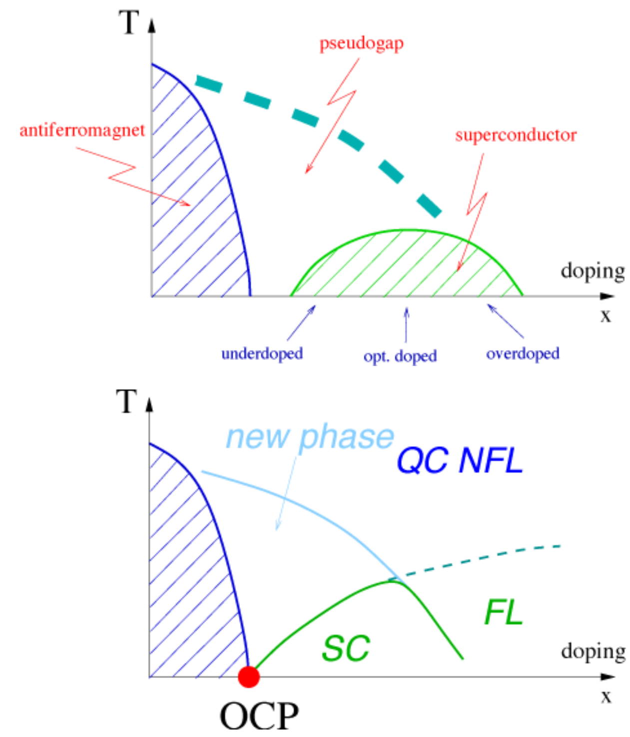

Figure 1

Top: The experimental phase diagram of high temperature superconductors. The understanding of the pseudogap phase is currently a topic of high interest.

Bottom: The theoretical phase diagram that emerges from the analysis of the spin-fermion model near the antiferromagnetic quantum-critical point (QCP). The normal state region (above the blue line) is divided into a Fermi liquid (FL) region, where fermions behave qualitatively as free particles, and quantum-critical, non-Fermi liquid (QC NFL) region, where fermions are nearly localized. The pairing of FL fermions yields a true superconductivity (SC), while the pairing of localized fermions creates spin singlets but does not give rise to a supercurrent. We identify the theoretical NEW PHASE with the pseudogap phase.

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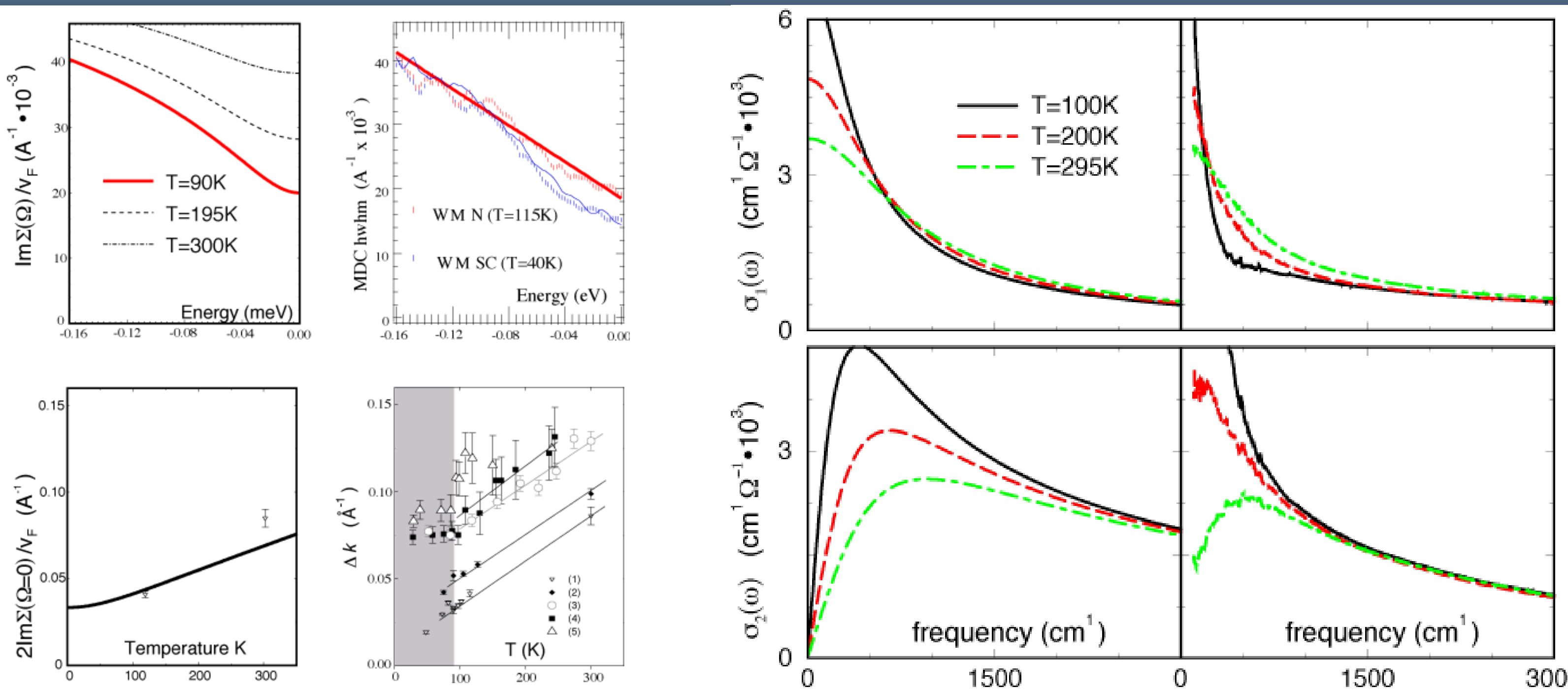

Figure 2

Some theoretical results for the normal state in comparison with the experimental photoemission and conductivity data. Left figure -- The fermionic self-energy vs frequency at a given temperature (upper panel), and vs temperature at a given frequency (lower panel). In the upper panel, the theoretical red line and the experimental blue line are for the same temperature. Right figure -- the theoretical and experimental results for the the real and imaginary parts of the optical conductivity. The theory has no adjustable parameters (the two input parameters are both fixed by other experimental data).

Educational

•Three graduate students.

•One postdoctoral associate (Artem Abanov).

The graduate students work and get training on various issues related to strongly interacting electronic systems (Raman scattering, low-dimensional magnetic systems, transport properties and condensation energy of superconductors). The postdoc collaborated with me on all issues related to the magnetic scenario for the cuprates.

Collaborators over the last three years

A. Abanov, N. Shannon, A. Finkelstein, B. Altshuler, J. Schmalian, O. Tchernyshov, B. Janko, M. Norman, M. Eschrig, A. Donkov, N. Gemelke